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Procedia Technology 4 (2012) 207 – 214

Procedia
Technology

C3IT-2012

Performance Comparison of Two Different Energy Conservation Mac Protocols

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Abstract

In Wireless Sensor Networks (WSN), neglecting the effects of varying channel quality can lead to an unnecessary wastage of precious battery resources. This can result in the rapid depletion of sensor energy and partitioning of the network. Fairness is a critical issue when accessing a shared wireless channel and fair scheduling must be employed to provide proper flow of information in WSN. In this paper, a channel adaptive MAC protocol with a traffic-aware dynamic power management algorithm is developed for efficient packet scheduling and queuing in a sensor network, with time varying characteristics of wireless channel taken into consideration. To avoid buffer overflow and achieve fairness for the poor quality nodes, a Load prediction algorithm is designed. In addition to these, a traffic aware dynamic power management scheme is also designed to minimize energy consumption by continuously turning off the radio interface of unnecessary nodes that are not included in the routing path. By Simulation results, the proposed protocol is seen to achieve high Throughput and fairness while reducing the energy consumption when compared to a traffic adapted sleep/listening MAC protocol

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Keywords: Sensor networks; Energy; Fairness; Throughput; Bandwidth

1. Introduction

1.1 Wireless Sensor Networks (WSN)

Sensor networks are dense wireless networks of small, low-cost sensors, which have the ability to collect and disseminate environmental data. Wireless sensor networks facilitate monitoring and controlling of physical environments from remote locations with better accuracy. They have applications in a variety of fields such as environmental monitoring, military purposes and also gathering sensing information in inhospitable locations. Sensor nodes have various energy and computational constraints because of their inexpensive nature and ad hoc method of deployment [1].

Energy consumption is the most crucial factor affecting the life of a sensor network because usually sensor nodes are driven by battery and have very low energy resources. This makes energy optimization

more complicated in sensor networks because it involves not only reduction of energy consumption but also prolonging the life of the network as much as possible.

Fairness is a critical issue when accessing a shared wireless channel. Fair scheduling must then be employed in WSNs to provide proper flow of information. A number of fair scheduling schemes exist in the literature; in which some are centralized, and others are distributed. In general these fair scheduling schemes determine appropriate weights in order to meet the QoS criteria. In most schemes weights are assigned and not updated for dynamic network conditions [2].

1.2. Existing MAC Protocols for Wireless Sensor Networks

MAC protocols can be classified from four perspectives such as contention-based, TDMA-based, hybrid, and cross layer MAC [3]. The following wide range of MAC protocols which are defined for sensor networks are described briefly by stating the essential behavior of the protocols wherever possible [4].

- Sensor-MAC (S-MAC) [4]
- Wise MAC [4]
- SIFT [4]
- Timeout-MAC (T-MAC) / Dynamic Sensor-MAC (DSMAC) [4]
- Traffic-Adaptive MAC Protocol (TRAMA) [4]
- IEEE 802.11 [5]
- Aloha with Preamble Sampling [5]
- Berkeley Medium Access Control (B-MAC) [5]
- PAMAS: Power Aware Multi-Access Signaling [5]
- Optimized MAC [5]
- Data Gathering MAC (D-MAC) [5]
- Self Organizing Medium Access Control for Sensor Networks (SMACS) [5]
- Energy Aware TDMA Based MAC [5]

1.3. MAC Layer Issues in Wireless Sensor Networks

The various design issues of the MAC protocols suitable for sensor network environment are [6]:

1. A MAC protocol should avoid collisions from interfering nodes, over-emitting, overhearing, control packet overhead and idle listening
2. Scalability, Adaptability and decentralization are other important criterions in designing a MAC protocol. The sensor network should adapt to the changes in the network size, node density and topology.
3. A MAC protocol should have minimum latency and high Throughput when the sensor networks are deployed in critical applications.
4. Since the nodes are deployed randomly, nodes from highly dense area may face high contention among themselves when reporting events resulting in high packet loss. So there should be uniformity in reporting the events by a MAC protocol.

There is no protocol accepted as a standard, although there are various MAC layer protocols proposed for sensor networks. One of the reasons behind this is that, the MAC protocol choice will, in general, be application-dependent, which means that there will not be one standard MAC for sensor networks. Another reason is the lack of standardization at lower layers (physical layer) and the (physical) sensor hardware. Some of the issues in the existing MAC protocols are described below [4]:

1. TDMA includes clock drift problems and decreased Throughput at low traffic loads due to idle slots. Also it is not easy to change the slot assignment within a decentralized environment for traditional TDMA, since all nodes must agree on the slot assignments.
2. In CSMA, additional collision avoidance or collision detection methods should be employed to handle the collision possibilities.
3. FDMA increases the cost of the sensor nodes due to the additional circuitry requirement involved in the need for dynamically communicating with different radio channels,
4. In CDMA, high computational requirement is a major obstacle for attaining less energy consumption in sensor networks. Also, there has been limited effort to investigate source and modulation schemes, particular signature waveforms, designing simple receiver models, and other signal synchronization problems.
5. In S-MAC, the duration of a listen period is always fixed and therefore causes unnecessary energy wastage [7].
6. For solving this problem, another protocol named T-MAC has been proposed. The down-side of T-MAC's aggressive power conserving policy is that nodes can go to sleep rather early, resulting in increased latency and lower Throughput [7].
7. Data-gathering MAC (DMAC) is another protocol that uses adaptive duty cycle. While DMAC outperforms TASL [15] in terms of latency, Throughput and energy efficiency, it remains to be seen if DMAC can support communication paradigms other than converge cast [8].

2. Related Work

Tijs van Dam et al [7] have described T-MAC, a contention-based Medium Access Control protocol for wireless sensor networks that can be exploited to reduce energy consumption by introducing an active/sleep duty cycle.

Gang Lu et al [8] have proposed Data-gathering MAC (DMAC), an energy efficient and low latency MAC that is designed and optimized for data gathering trees in wireless sensor networks. DMAC solve the interruption problem by giving the active/sleep schedule of a node an offset that depends upon its depth on the tree. A data prediction mechanism is further proposed and more to send (MTS) packets are used in order to alleviate problems pertaining to channel contention and collisions.

Injong Rhee et al [9] have proposed a new hybrid MAC scheme, called Z-MAC (Zebra MAC), for sensor networks that combine the strengths of TDMA and CSMA while offsetting their weaknesses. The main feature of Z-MAC is its adaptability to the level of contention in the network – under low contention; it behaves like CSMA, and under high contention, like TDMA. It is also robust to dynamic topology changes and time synchronization failures commonly occurring in sensor networks.

Tao Zheng et al [10] have proposed Pattern-MAC (PMAC) protocol, a novel adaptive MAC protocol for wireless sensor networks that adaptively determines the sleep-wake up schedules for a node based on its own traffic, and the traffic patterns of its neighbors, instead of having fixed sleep-wakeups.

Michael Buettner et al [11] have presented X-MAC, a low power MAC protocol for wireless sensor networks, which employs a shortened preamble approach that retains the advantages of low power listening, namely low power communication, simplicity and a decoupling of transmitter and receiver sleep schedules.

Joseph Polastre et al [12] have proposed B-MAC, a carrier sense media access protocol for wireless sensor networks that provides a flexible interface to obtain ultra low power operation, effective collision avoidance and high channel utilization. To achieve low power operation, B-MAC employs an adaptive preamble sampling scheme to reduce duty cycle and minimize idle listening.

Stephan Mank et al [13] have proposed MLMAC; a novel TDMA based MAC protocol that can react on changing radio neighborhoods in mobile networks. MLMAC does not depend on a gateway to start the synchronization; instead, it is fully dynamic.

3. Channel Adaptive MAC Protocol

3.1. Protocol Overview

Packet transmission through a link of high quality consumes less energy than that needed through a “bad” link. Based on this observation, in the proposed scheme, each sensor node should possess the ability to decide the state of its communication unit with respect to the current condition of the wireless link between it and the sink. Every node estimates the channel state and link quality for each contending flow. To represent the channel state and link state at the LLC queue, a flag is initiated. The flag can take three values: Good, Bad or Probe. The proposed protocol calculates a combined weight value based on these flags. Then transmission is allowed only for those nodes with weight greater than a minimum threshold value. Nodes attempting to access the wireless medium with a weight value less than the threshold value will be allowed to transmit again when their weight becomes high.

By intelligently switching to sleep mode whenever possible will generally create significant energy savings. A traffic aware dynamic power management scheme is designed. The design goal of the proposed dynamic power management scheme is, to minimize energy consumption by continuously turning off the radio interface of unnecessary nodes that are not included in the routing path. For this, the nodes are categorized into three types depending upon the state defined by data transmission: Current Transmitting Node (CTN), Future Transmitting Node (FTN), and No Transmitting Node (NTN). A state may dynamically change whenever data traffic is transmitted. Then, only the CTN and FTN nodes are asked to wake up, while other NTN nodes can continuously remain in their sleep modes.

3.2. Estimating the Link Quality

The link quality or link metrics such as: Bandwidth, energy is measured by the MAC layer. Link metrics are then introduced to IP routing protocol. The link metrics are taken into account in order to calculate the path for the new incoming flow by the routing algorithm.

The residual Bandwidth and energy information are determined by every WSN node. In the route discovery process, each node estimates a combined weight value based on its residual Bandwidth and energy and is transmitted across in the route request packet.

It estimates the residual Bandwidth R_{bw} as

$$R_{bw} = C_{bw} - U_{bw} \quad (1)$$

Where,

C_{bw} - channel Bandwidth,

U_{bw} - used or consumed Bandwidth,

Similarly the residual energy R_e is estimated as

$$R_e = (C_e - U_e) \quad (2)$$

Where,

C_e – Initial energy,

U_e - used or consumed energy,

Now the Link Weight LQ can be calculated as the combined sum of residual Bandwidth and energy

3.3. Estimation of Channel Condition

Every node estimates the channel conditions for each contending flow. To represent the channel state at the Link Layer (LL) queue a flag is initiated. The flag can take three values: GOOD, BAD and PROBE

GOOD: A flag is set as GOOD by the node when it receives, from the following flow: (i) a MAC-layer acknowledgment in response to a data frame, (ii) a CTS frame in response to an RTS frame, or (iii) an error-free data frame or RTS.

BAD: The node sets the flag to BAD after a transmission failure.

PROBE: The node switches the flag from BAD to PROBE when a configurable timeout, that we named Ptimer, expires. Ptimer starts to run whenever the channel state switches to BAD, and its initial value is doubled when a transition from PROBE to BAD occurs. The duration of Ptimer is reset to its initial value upon a transition from PROBE to GOOD

3.4. Traffic Aware Dynamic Power Adjustment

The nodes are grouped into the following categories:

Current Transmitting Node (CTN): Any node currently participating in the actual data transmission.

Future Transmitting Node (FTN): Any node to be involved in the actual data transmission. .

No Transmitting Node (NTN): Any node that is not included in a routing path and hence not involved in the actual data transmission at all.

The new RTS and CTS packet add only one field to the original packets. The newly added field in RTS is Final destination address, by which the receiver's routing agent can search for the next hop address. The new field of CTS is FTN address and it informs which node is FTN to its neighbours.

3.5. Adaptive Threshold Adjustment Scheme

To avoid buffer overflow and achieve fairness for the poor quality nodes, a Load prediction algorithm is designed. In the Load prediction algorithm, the minimum quality threshold W_m is adaptively adjusted based on the current incoming traffic load TL. For this, the buffer and queue length values of the node are continuously monitored for a specified period. Based on the queue length variations in that period, the traffic load TL can be predicted. Whenever there is a buffer overflow, the threshold is adaptively adjusted, based on the predicted traffic load. i.e., threshold will be reduced or increased if the traffic load is increasing or decreasing, respectively. Thus, a balance between energy efficiency and fairness is achieved.

The process of buffering packets until the channel threshold constraint is satisfied, is applicable only for nodes with better link quality, since they can always get the most Bandwidth shares. As a result of this, the nodes with bad link quality have to wait until its channel quality recovers, leading to starvation. Buffer overflow can be prevented by predicting the future traffic load. This can be achieved by constantly measuring the queue length and its variation

4. Performance Evaluation

4.1 Simulation Model and Parameters

Network Simulator (NS2) [14] is used to simulate the proposed protocol. In the simulation, the channel capacity of sensor nodes is set to the same value: 2 Mbps. Sensor nodes are deployed in a 1000 meter x 1000 meter region for 14 seconds simulation time. The number of nodes is varied as 25, 50....100. Initially the nodes are placed randomly in the specified area. The base station is assumed to be situated 100 meters away from the above specified area. The initial energy of all the nodes is assumed as 4 Joules. All nodes have the same transmission range of 250 meters. The simulated traffic is CBR with UDP source and sink.

The simulation settings and parameters are summarized in Table 1.

Table 1: Simulation Settings

No. of Nodes	25, 50, 75 and 100
Area Size	1000 X 1000
Radio Range	250m
Routing Protocol	AODV
Simulation Time	14 sec
Traffic Source	CBR
Packet Size	512 bytes
Transmit Power	0.395 w
Receiving Power	0.360 w
Idle Power	0.335 w
Initial Energy	4.0 J
No. of. Flows	4
Rate	100kb,200kb,.....500kb
Error Rate	0.01,0.02,....0.05

4.2. Results

The proposed AEMAC protocol is compared with the TASL [15] protocol.

4.2.1. Effect of Varying Channel Error Rates

In the initial experiment, the channel error rates are varied as 0.01, 0.02, 0.03, 0.04 and 0.05, keeping the number of nodes as 50, number of flows as 4 and rate as 100kb. The idea is to determine the performance of the protocols AEMAC and TASL, in error prone situations which normally exist in wireless sensor networks.

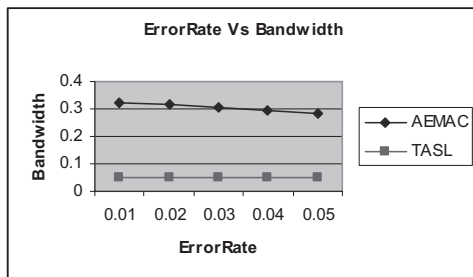


Fig.1. Error Rate Vs Bandwidth Received

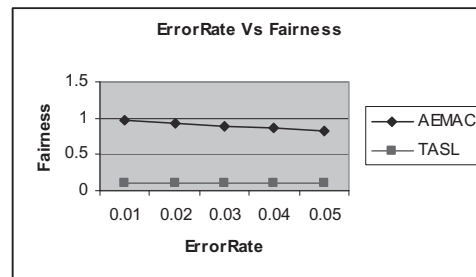


Fig. 2. Error Rate Vs Fairness

Figure 1 gives the aggregated Bandwidth for the AEMAC and TASL protocols. When Error rate increases, the Bandwidth received by the nodes in the network decreases even if efficient schemes are incorporated to deal with the errors. The scheme which can successfully provide reliable data transmission, in spite of the channel errors in the network, will exhibit the superior performance. As per the proposed algorithm, the nodes with high weight values are allowed to transmit when there is a channel error. So the received Bandwidth for proposed protocol is more when compared with other TASL. As seen in the figure, the Bandwidth received is higher for the AEMAC scheme.

Figure 2 gives the fairness index for the AEMAC and TASL protocols. When error rate increases, the nodes in the network could not be provided equal fairness and so the fairness value decreases. AEMAC scheme has adopted an adaptive threshold adjustment scheme to provide fairness. From the figure, it can be seen that AEMAC achieves more fairness when compared with TASL.

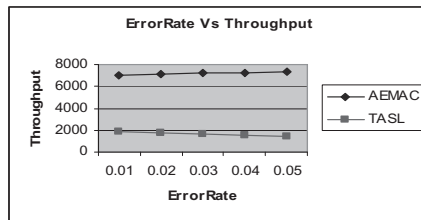


Fig. 3. Error Rate Vs Throughput

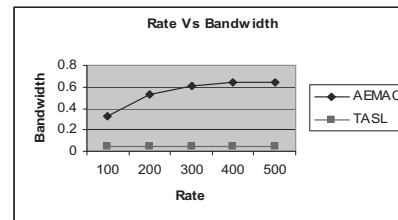


Fig. 4. Rate Vs Bandwidth Received

Figure 3 gives the Throughput of both the protocols. The rate of service of messages by the communication system gets adversely affected on an increase in the Error rate. On an increase in the Error rate, most power saving schemes drive most of the nodes to the sleep state. Now discovering energy efficient reliable paths to the destination becomes difficult leading to a degraded Throughput. Throughput level is much higher for AEMAC scheme proving its superior performance, as depicted in the figure.

4.2.2. Effect of Varying Transmission Rate

In the final experiment, the transmission rate is varied from 100kb to 500kb, keeping the error rate as 0, number of flows as 4 and number of nodes as 50. Effect of varying transmission rate on Bandwidth, Throughput and Energy consumption is to be analyzed.

Figure 4 gives the aggregated Bandwidth for the AEMAC and TASL protocols. When transmission rate is increased, more data is liberated into the network. The network which uses a better protocol will be able to utilize more Bandwidth by finding reliable paths to the destination. From the figure, it can be seen that AEMAC has received more Bandwidth when compared with TASL.

Figure 5 gives the Throughput of both the protocols. When transmission rate increases, more data will be serviced by the network and transferred to the destination. So Throughput increases. The network which uses a better protocol will be able to provide a better Throughput. AEMAC scheme involves the data transfer from a node only if the link quality, channel quality and energy level are good. So data transmission can be conducted effectively. As we can see from the figure, the Throughput is more in the case of AEMAC than TASL.

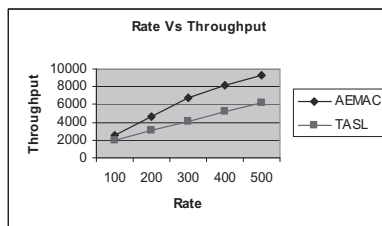


Fig. 5. Rate Vs Throughput

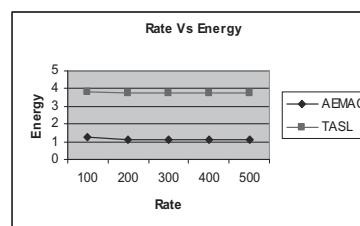


Fig. 6. Rate Vs Energy

Figure 6 shows the results of energy consumption for the protocols. Energy consumption decreases for both the schemes AEMAC and TASL, on an increase in the Transmission Rate. Overall Energy consumption of AEMAC scheme is much lesser compared to the TASL scheme, proving its success in finding energy efficient paths and routing the packets effectively and reliably to the destination. It can be inferred that, in any network the energy consumption which is the main problem in wireless sensor networks, can be decreased on an increase in the transmission rate.

5. Conclusions

In this paper, a channel adaptive MAC protocol with a traffic-aware dynamic power management algorithm is developed, which calculates a combined weight value based on the channel

state and link quality. Then transmission is allowed only for those nodes with weights greater than a minimum quality threshold and nodes attempting to access the wireless medium with a low weight value will be allowed to transmit again when their weight becomes high. To avoid buffer overflow and achieve fairness for the poor quality nodes, a Load prediction algorithm is designed, in which the minimum quality threshold is adaptively adjusted based on the current incoming traffic load. The energy consumed in an idle mode is less than Active mode, but significantly greater than in the sleep mode. Hence, intelligently switching to sleep mode whenever possible will generally create significant energy savings. For this, a traffic aware dynamic power management scheme is designed to minimize energy consumption. In this scheme, the radio interface of nodes that are not included in the routing path is continuously turned off. By Simulation results, it is seen that, the proposed protocol achieves better Throughput and fairness while reducing the energy consumption.

References

1. Archana Bharathidasan *et al*, "Sensor Networks: An Overview", Survey paper, IEEE Infocom, 2004.
2. James W. Fonda *et al*, "Adaptive Distributed Fair Scheduling and Its Implementation in Wireless Sensor Networks", IEEE International Conference on Systems, Man, and Cybernetics, October 8-11, 2006, Taipei, Taiwan, 2006.
3. Li Deliang and Peng Fei, "Energy-efficient MAC protocols for Wireless Sensor Networks", Proceedings of the IEEE Infocom, New York, USA, 2009.
4. Ilker Demirkol *et al*, "MAC Protocols for Wireless Sensor Networks: a Survey", Communications Magazine, vol-44, IEEE, April, 2006
5. Rajesh Yadav *et al*, "A Survey of MAC Protocols for Wireless Sensor Networks", UbiCC journal, Vol-4, No 3, August 15, 2009.
6. Gowrishankar.S *et al*, "Issues in Wireless Sensor Networks", Proceedings of the World Congress on Engineering, Vol I, WCE, July 2 - 4, 2008, London, U.K.
7. Tijs van Dam and Koen Langendoen, "An Adaptive Energy Efficient MAC Protocol for Wireless Sensor Networks", Proceedings of the 1st international conference on Embedded networked sensor systems, Los Angeles, California, USA, 2003.
8. Gang Lu *et al*, "An Adaptive Energy-Efficient and Low-Latency MAC for Data Gathering in Sensor Networks", 2004.
9. Injong Rhee *et al*, "Z-MAC: a Hybrid MAC for Wireless Sensor Networks", IEEE/ACM Transactions on Networking (TON), Vol 16, Issue 3, June 2008.
10. Tao Zheng *et al*, "PMAC: An adaptive energy-efficient MAC protocol for Wireless Sensor Networks", Proceedings of the 19th IEEE International Parallel and Distributed Processing Symposium (IPDPS'05) - Workshop 12 - Volume 13, 2006.
11. Michael Buettner *et al*, "X-MAC: A Short Preamble MAC Protocol for Duty-Cycled Wireless Sensor Networks", Conference On Embedded Networked Sensor Systems, Proceedings of the 4th international conference on Embedded networked sensor systems, Boulder, Colorado, USA, 2006.
12. Joseph Polastre *et al*, "Versatile Low Power Media Access for Wireless Sensor Networks", Conference On mbedded Networked Sensor Systems, Proceedings of the 2nd international conference on Embedded networked sensor systems Baltimore, MD, USA, 2004.
13. Stephan Mank *et al*, "An adaptive TDMA based MAC Protocol for Mobile Wireless Sensor Networks", Proceedings of the 2007 International Conference on Sensor Technologies and Applications SENSORCOMM'07.
14. Network Simulator, <http://www.isi.edu/nsnam/ns>
15. Yuan Yang, Fu Zhen, Tae-Seok Lee, and Myong-Soon Park "TASL: A Traffic-Adapted Sleep/Listening MAC Protocol for Wireless Sensor Network" International Journal of Information Processing Systems, Vol.2, No.1, March 2006.